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PROGRESSIVE-RATIO SCHEDULES: EFFECTS OF LATER SCHEDULE REQUIREMENTS ON EARLIER PERFORMANCES

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Four rats were studied with variants of a progressive-ratio schedule with a step size of 6 in which different terminal components followed completion of the 20th ratio: (a) a reversal of the progression, (b) a fixed-ratio 6 schedule, or (c) extinction. Responding in the progressive-ratio components of these schedules was compared to performances under conventional progressive-ratio baselines. Under baseline conditions, postreinforcement pauses increased exponentially as a function of increasing ratio size, whereas running rates showed modest declines. The procedure of linking the progressive-ratio schedule to the reversed progression or to the fixed-ratio component resulted in decreased pausing. Linking the progressive-ratio schedule to the extinction component had the opposite effect, that of producing weakened progressive-ratio performances as evidenced by increased pausing. Subjects whose responses were reinforced on half of the ratios also showed exponential increases; however, pauses were substantially shorter following ratios on which the reinforcer was omitted. The results suggested that progressive-ratio pausing reflects the influence of remote as well as local contingencies.

Key words: progressive-ratio schedule, fixed-ratio schedule, postreinforcement pause, running rate, multiple schedule of reinforcement, lever press, rats

Lattal (1991) noted that "schedules of reinforcement are prescriptions for arranging reinforcers in time and in relation to behavior" (p. 87). Each prescription is different, and these differences provide a basis for understanding the controlling influences of reinforcement. The unique feature of the progressive-ratio (PR) schedule is the requirement of an increasing number of responses for each successive reinforcer. For example, a PR schedule with a step size of 5 delivers the first reinforcer upon completion of the first five responses, the second after 10 responses, the third after 15 responses, and so on. The session ends when the ratio becomes too large for responding to be maintained (the breaking point). As shown in early research (Hodos, 1961; Hodos & Kalman, 1963), the characteristic PR response pattern resembles that for fixed-ratio (FR) schedules. The initial portion of the interreinforcement interval is occupied by a pause, but following the first response a high rate of responding ensues until delivery of the next reinforcer. In addition, for both PR and FR schedules, the duration of the pause following the reinforcer increases as a function of the size of the individual ratio.

Although PR schedules have not been studied in as much detail as simpler schedules, they are of growing interest for similar reasons. One is that schedules are needed as baselines for the study of other processes, such as the reinforcing potential of different events. In the case of the PR schedule, the breaking point provides a measure of the reinforcing value of food substances, such as sweetened milk (Hodos & Kalman, 1963), or of commonly abused drugs, such as cocaine (Griffiths, Bradford, & Brady, 1979). Schedules also provide models of contingencies encountered outside the laboratory. The diminishing returns that characterize the PR schedule have suggested parallels to those governing an animal's search for food within its natural habitat (so-called foraging behavior; Hackenberg, 1998), as well as contingencies encountered in the world of human affairs (e.g., athletic events, such as the high jump competition).

The present experiment was guided by a third role played by schedule research: to clarify the sources of the control exerted by

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the schedule contingencies themselves. Efforts to analyze the PR schedule must take into account two sets of contingencies. At the local level are the individual ratios that comprise the units of the schedule, but superimposed on these contingencies are those embedded in the progression of increasing ratio sizes. Support for the view that PR performances are governed by the local contingencies can be found in similarities between PR and FR performances, most notably the finding that postreinforcement pausing varies as a function of the size of the ratio. Alternatively, influences of the progression are suggested by evidence that FR responding is controlled by characteristics of the upcoming ratio, including its size (Baron & Herpolsheimer, 1999; Crossman, 1968) and the magnitude of the reinforcer (Perone & Courtney, 1992).

The present procedures were a step toward disengaging the influences of local and upcoming contingencies. We accomplished this by exposing 4 rats to a two-component multiple schedule, each of whose components appeared once during the session. The first part of the session always contained a standard PR 6 (a step size of 6) schedule in which completion of each ratio resulted in food reinforcement. Completion of the 20th ratio produced the second component of the schedule: a stimulus change and a new set of contingencies. In one condition, the terminal component contained a reversed progression; that is, when a ratio size of 120 was reached in the initial component, the first ratio of the terminal component was reduced to 114 responses, the second to 108, and so on until the initial ratio of 6, at which point the session ended. In a second condition, the terminal component contained a less demanding FR 6 schedule for the subsequent 19 ratios of the session. Finally, a third condition contained extinction in the terminal component, so that further reinforcers were no longer available following the 20th ratio. The data analyses centered on comparing responding in the PR component of these compound schedules with responding during the first 20 ratios of a conventional PR 6 schedule that ended when the breaking point criterion was met.

To determine the generality of the findings, we also introduced the experimental conditions on a percentage reinforcement baseline. The procedure for 2 of the subjects was to intermittently reinforce 50% of the ratios rather than 100%, as is usually the case. In the case of FR schedules, omission of reinforcement is known to have major effects, primarily resulting in a marked reduction in the duration of the subsequent postreinforcement pause (McMillan, 1971). Percentage reinforcement has not been studied in conjunction with PR schedules, however, and this led us to examine the effects of this manipulation on the growth of postreinforcement pausing, and the extent to which these effects modify control by remote contingencies.

METHOD

Subjects

Four experimentally naive male albino rats (Sprague-Dawley derived) were approximately 6 months old at the start of the experiment. Food deprivation was accomplished by scheduling 1-hr free-feeding periods shortly after the experimental sessions (Hurwitz & Davis, 1983). Animals were housed individually with free access to water, and illumination within the vivarium followed a 16:8 hr light/dark cycle.

Apparatus

Two single-lever rodent chambers (Grason-Stadler, E3125; 29 cm by 24 cm by 19 cm) were enclosed within sound-attenuating ventilated chests. The lever, which required a minimum force of approximately 0.35 N to operate, was centered on the front wall, 9.5 cm above the grid floor. Each response was accompanied by a feedback stimulus (momentary interruption of the background white noise). The food reinforcer (45-mg Noyes pellets) was delivered to a recessed food cup positioned at floor level directly below the lever. The cup was accessed through an opening in the wall. The chamber was illuminated by two shielded 3-W lights mounted outside the Plexiglas walls, one at the front of the right wall and the other at the rear of the left wall. Extraneous sounds were masked by white noise and the sound of the ventilating fan. The chambers were linked to microcomputers and recording equipment in an adjacent room.

Table 1

Experimental conditions and number of sessions under each. Under the extinction condition, sessions were not always completed; the number of uncompleted sessions is given in parentheses. Numbers in brackets signify the order of conditions for each subject. Throughout, R10 and R12 were trained under a 100% schedule in which every ratio was reinforced; for R09 and R11, 50% of the ratios were reinforced.

Condition	R10			R12			R09			R11	
PR training											
Preliminary	34		[1]	34		[1]	61		[1]	32	[1]
Baseline 1	8		[2]	9		[2]	8		[2]	8	[2]
Baseline 2	20		[7]	24		[7]	20		[7]	20	[7]
Baseline 3	24		[10]	22		[10]	12		[10]	26	[10]
PR reversal											
Preliminary	19		[3]	14		[3]	17		[3]	17	[3]
Mixed 1	12		[4]	12		[4]	12		[4]	12	[4]
Multiple	16		[5]	16		[5]	16		[5]	17	[5]
Mixed 2	12		[6]	12		[6]	12		[6]	16	[6]
PR fixed ratio											
Mixed	12		[11]	12		[8]	12		[11]	16	[8]
Multiple	11		[12]	12		[9]	16		[12]	12	[9]
PR extinction											
Mixed	13	(9)	[8]	12	(6)	[11]	11	(4)	[8]	12	[11]
Multiple	12	(3)	[9]	10	(10)	[12]	12	(5)	[9]	12	[12]

Procedure

Sessions were conducted 6 or 7 days per week. At the start of a session, the test chamber was dark and silent except for the sound of the ventilating fan, and the lever was inoperative. After a 1-min delay, the session began. Initiation of the reinforcement schedule was accompanied by activation of the lever, illumination of both chamber lights, and continuous white masking noise. When the session ended, the lever was deactivated and the chamber light and white noise were turned off.

The following events occurred when a reinforcer was delivered: The white noise terminated, a 2000-Hz tone sounded for 2 s, and two food pellets were dropped into the food cup 0.50 s and 1.25 s after onset of the tone. Responses in the presence of the tone were rare; any that did occur were not counted toward the response requirement of the next ratio.

Preliminary training. The sequence of conditions is summarized in Table 1. After the lever-press response was shaped by the method of reinforcing successive approximations, the preliminary training phase ensued in which animals were exposed to increasingly demanding PR schedules. The final schedule, the one used as the baseline during the remainder of the experiment, was PR 6. The first reinforcer (two pellets) was delivered upon completion of six responses, the second after 12 responses, the third after 18 responses, and so on. The baseline sessions ended when 10 min had elapsed without a response (the breaking point). During the baseline phases of the experiment, both the front and rear chamber lights were on continuously.

Percentage reinforcement conditions. Midway in the preliminary training phase, subjects were assigned to one of two percentage reinforcement conditions. Two rats (R10 and R12) continued to receive 100% reinforcement (two pellets per ratio) throughout the rest of the experiment. The remaining 2 rats (R09 and R11) were exposed to a 50% reinforcement schedule in which the two-pellet reinforcer was omitted for half of the ratios. On the nonreinforced ratios, the 2-s tone sounded but the pellets were not delivered. The specific ratios when responding was not reinforced were scheduled in an unsystematic order that changed from day to day. The 50% schedule was introduced over a series of sessions during which the percentage was gradually reduced from 100% to 50%.

Reversal of progression. The series of compound schedules was introduced when PR responding was well established. The general procedure was the same in each case: The initial component contained the baseline PR

6 schedule, and, upon completion of the 20th ratio (120 responses), the terminal component with a new set of contingencies ensued. Under the reversal condition the progression decreased in steps of six (114, 108, 102, etc.) until a final value of six was reached, at which point the session ended (a total of 39 ratios). For the data reported here, different stimuli were correlated with the two schedule components. For 2 subjects (R09 and R12), the front light blinked and the rear light was off during the initial component, and the rear light blinked and the front light was off during the second component. For the other 2 subjects (R10 and R11), these stimulus conditions were counterbalanced. As shown in Table 1, training with the reversal point of 20 was preceded by preliminary observations with other values. In addition, during this and subsequent phases, data were collected with a mixed variant of the reversal procedure in which the two chamber lights were on continuously. (These findings were not as clear as when the stimuli defined the two components and are not reported below.)

Extinction and FR 6. In subsequent conditions, extinction and FR 6 were placed within the terminal component. These conditions were introduced following exposure to the reversal condition and additional baseline training (see Table 1). Under the extinction condition, no further responses were reinforced following the 20th ratio, and the session ended when 10 min had elapsed without a response. Under the FR 6 condition, responding on the subsequent 19 ratios was reinforced following completion of six responses. The order of the extinction and FR conditions also was counterbalanced: extinction then FR 6 for 2 subjects (R09 and R12) and FR 6 then extinction for the other 2 (R10 and R11). Other details were as described above. Exposure to the extinction and FR 6 conditions was separated by additional sessions with the conventional PR baseline, and the same correlations of chamber lights and components described earlier were in effect.

Stability criterion. Table 1 shows the number of sessions under each condition. Conditions were changed when overall pausing (the median pause for the session) was stable over the most recent eight sessions. The stability criterion required that the difference between the median of the first four and the last four sessions not exceed 10% of the overall median. Except for the first baseline phase, a minimum of 12 sessions was conducted under each condition (due to a procedural error, 11 sessions for R10 under Condition 12); additional sessions were conducted as needed depending on trends in day-to-day performances. During some of the sessions of the extinction condition, animals did not complete a sufficient number of ratios to enter the terminal extinction component (Table 1 gives the number of uncompleted sessions in parentheses). The performance of 1 of these animals (R12) deteriorated to the extent that usable data under the extinction condition could not be obtained.

RESULTS

Postreinforcement pauses and run times were recorded to the nearest second. Pauses were measured from the offset of the tone that accompanied the reinforcement cycle to the first response of the upcoming ratio (direct observations indicated that, with rare exception, the pellet was consumed by the time the tone was terminated). Run times, used to calculate running rates, were measured from the first to the last response of the ratio.

Pause data are summarized for each animal in Figure 1 (R10 and R12; 100% reinforcement) and Figure 2 (R09 and R11; 50% reinforcement). The following information will aid interpretation of the results. Baseline values represent the median latencies for each ratio in the progression during the last eight sessions of each baseline condition. Data from the multiple-schedule conditions are shown to the right. The first panel of each pair depicts performances during the initial component (PR), and the second panel presents performances during the terminal component (either reversal, FR 6, or extinction). For baseline and initial-component performances, the first ratio of the session was excluded from the analysis because it was not preceded by a reinforcer. For the 50% animals, pauses following reinforced and nonreinforced ratios are plotted separately.

In all cases, the latency values have been plotted on a logarithmic scale to accommodate the wide range of values, and the figures also show the best fitting functions yielded by a linear regression analysis. To aid interpre-

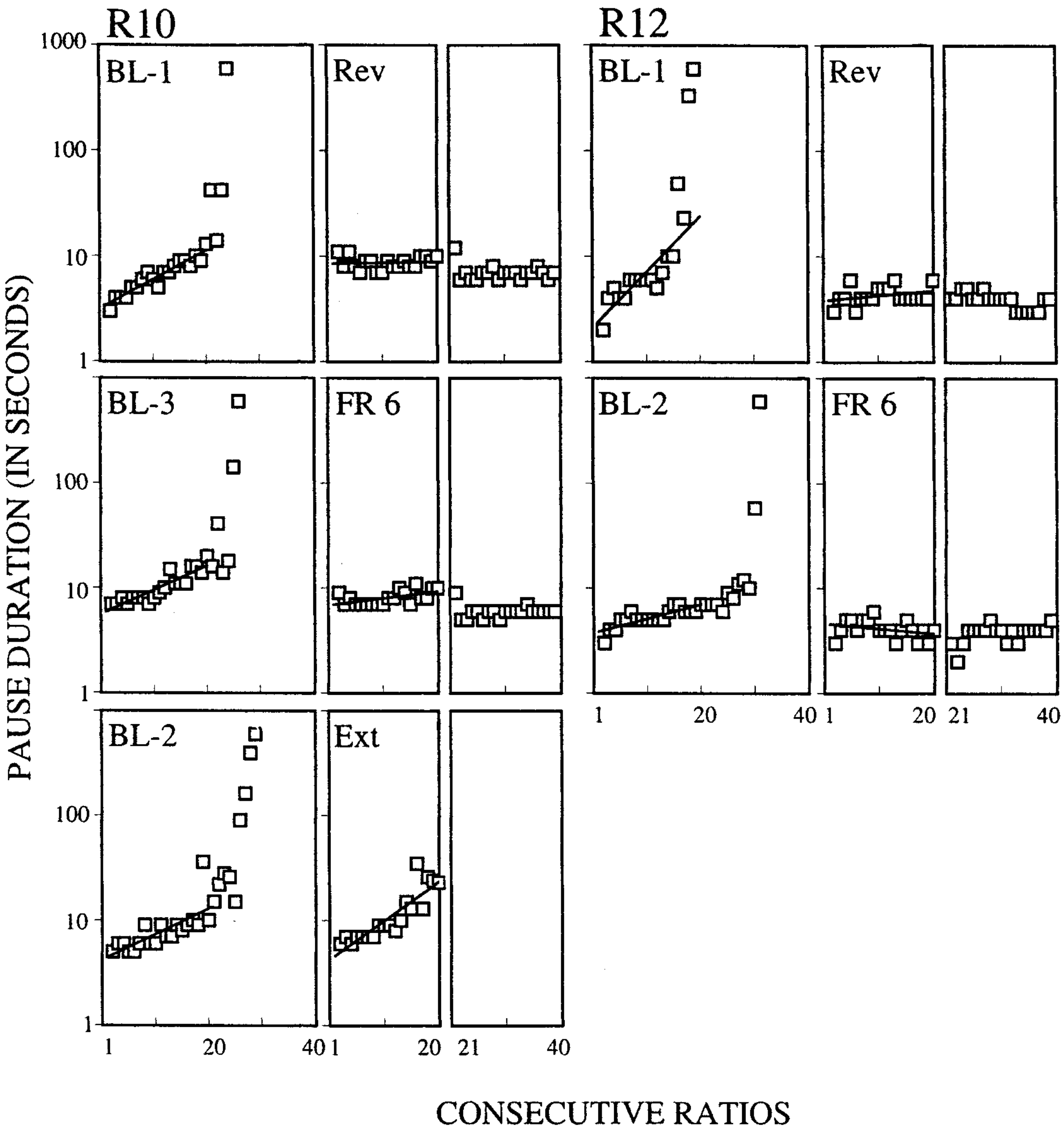

Fig. 1. Pause durations (in seconds) as a function of ratio size for R10 and R12. Baseline performances are shown in the three left panels. The three right panels depict performances under the multiple-schedule conditions in which the 20th ratio of the progression was followed by reversed, FR, and extinction schedules (R10) or by reversed and FR schedules (R12). Note that pause durations are plotted logarithmically. The solid lines show the best fitting linear functions for each subject's data.

tation, the exact slope and intercept values resulting from the curve-fitting procedures are summarized in Table 2 (R10 and R12) and Table 3 (R9 and R11). For the baseline data, these functions were based on performances during the 2nd through 20th ratio in the progression, that is, those ratios corresponding to the initial component under the multiple schedule condition. In some instances, however, there were abrupt increases in baseline latencies prior to the 20th ratio, and these discrepant values were excluded from the curve-fitting procedures (see Tables 2 and 3).

The results from the baseline conditions show that sequences of pauses followed a consistent pattern for all animals (Figures 1 and 2, left panels). When plotted on a log scale,

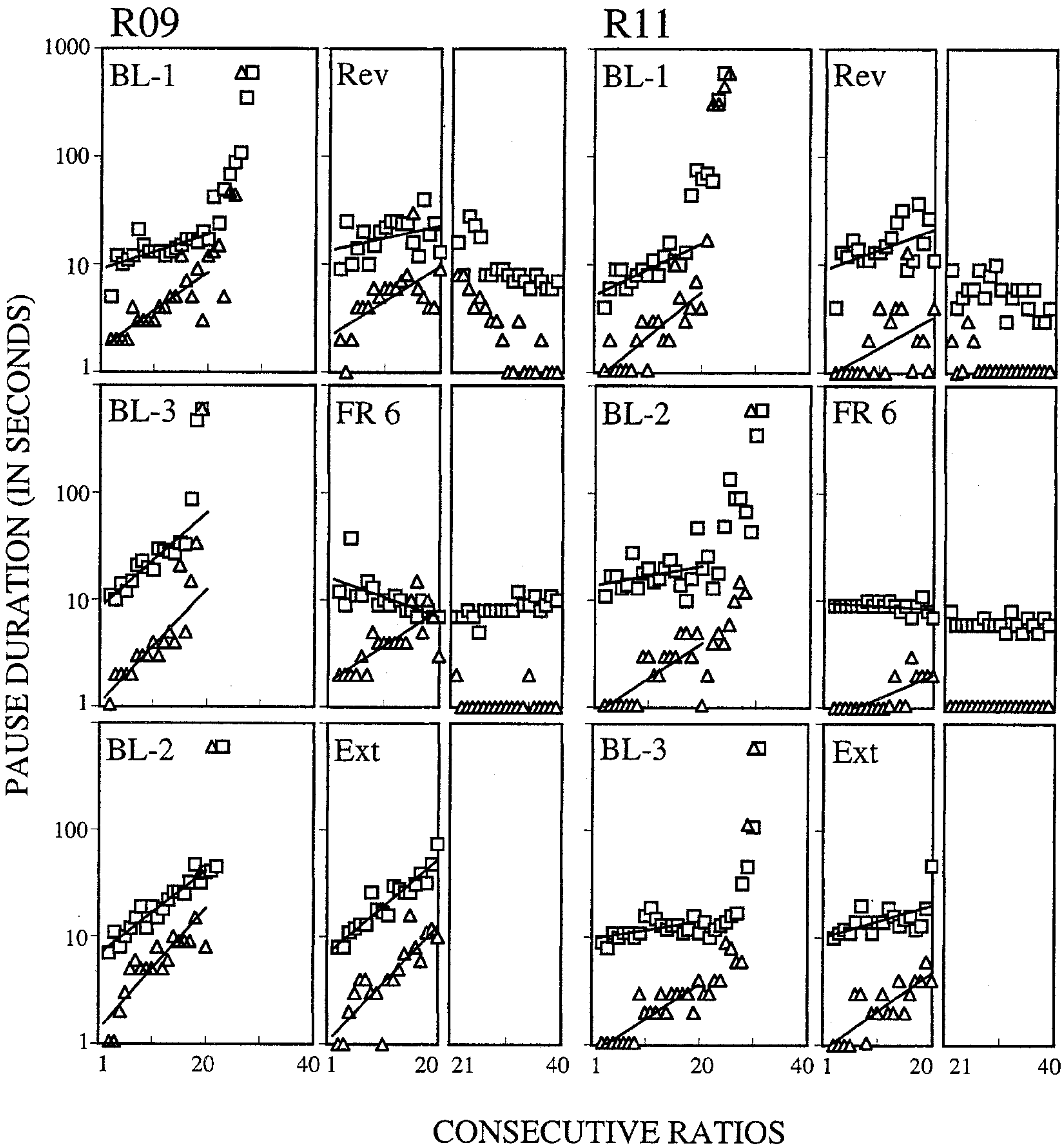

Fig. 2. Pause durations (in seconds) as a function of ratio size for R09 and R11. Baseline performances are shown in the three left panels. The three right panels depict performances under the multiple-schedule conditions in which the 20th ratio of the progression was followed by reversed, extinction, and FR schedules (R09) or by reversed, FR, and extinction schedules (R11). Responding was reinforced according to a 50% probability schedule. Pauses following reinforced ratios are designated by squares, and pauses following nonreinforced ratios are designated by triangles. Note that pause durations are plotted logarithmically. The solid lines show the best fitting linear functions for each subject's data.

pausing increased as a linear function of the ratio size throughout most of the range of ratios. The slope steepened markedly several ratios before the final breaking point, and this change was maintained until the session ended. Also noteworthy are the effects of omitting reinforcement on baseline performances under the percentage reinforcement condition (Figure 2, left panels). Pausing was markedly attenuated, rarely exceeding 10 s until the last few ratios of the schedule. However, reduced pausing was not accompanied

Table 2

Statistics from analyses of the data depicted in Figure 1 for R10 and R12, including slopes, intercepts, and the percentage change in slope from baseline (BL) to the succeeding experimental conditions: reversal (Rev), fixed ratio (FR), and extinction (Ext). Regression values are expressed in log units to make them comparable to those in the graphic presentations. Analyses are based on Ratios 2 through 20 of the PR schedule, except as noted.

Rat	Slope	Intercept	r^2	Change (%)
R10				
BL 1	0.028	0.524	.90	
Rev	0.001	0.927	.01	−96
BL 3	0.023	0.769	.81	
FR	0.006	0.842	.30	−74
BL 2	0.024	0.645	.51	
Ext	0.037	0.662	.78	+54
R12				
BL 1[a]	0.056	0.296	.69	
Rev	0.005	0.586	.09	−91
BL 2	0.013	0.586	.67	
FR	−0.005	0.659	.10	−138
BL 3				
Ext				

[a] Ratios 2 through 17.

by reduced rates of increase across the progression. If anything, the slopes of the functions tended to be steeper following nonreinforced ratios.

The linear relation between pause durations and ratio sizes also can be characterized as an exponential function. (When the logarithms of Y are plotted against the values of X, $\log Y = \log a + bX$, a linear relation indicates an exponential equation of the form, $Y = a10^{bx}$.) Questions can be raised, however, about the appropriateness of this description for some of the present data. Although the functions in Figures 1 and 2 generally appear to be linear, the proportions of the variances accounted for by the best fitting lines often are below what are usually deemed to be acceptable values (see r^2 values in Tables 2 and 3). Two considerations argue for adoption of a lenient criterion. First, the analysis was based on the individual ratios of the progression. No doubt, the functions would be more regular and r^2 values larger in an analysis that averaged groupings of the ratios within the progression. Second, the analysis had to cope with functions whose slopes were shallow. Reductions in the range of values of the Y variable work against the proportion of the variance that can be accounted for on the basis of the X variable. In the limiting case—a function with a slope of zero—variations in X cannot account for more than 0% of the variation in Y.

Results from the multiple-schedule conditions show that pausing in the first component of the schedule depended on the contingencies within the second component (Figures 1 and 2, middle panels). For all of the animals, the slopes of the pause-ratio functions decreased under the reversal and FR 6 conditions and increased under the extinction condition. These changes from baseline levels may be seen in percentage form in Tables 2 and 3. Under the reversal condition, the extent to which the slopes for the first 20 ratios decreased from the baseline ranged from −8% to −96%, and the median for the six comparisons was −33%. Decreases were yet more marked for the FR condition. The range was from −37% to −140%, and the median for the six comparisons was −103%. For 3 of the 4 animals, FR decreases exceeded those under the reversal condition (the exception was R10).

By comparison with the reversal and FR 6 conditions, pausing during the extinction condition was characterized by increased slopes. Although the magnitude of the changes was not as consistent, some degree of increase was apparent in all 4 animals. The values ranged from −7% to 87%, and the median change for all five extinction comparisons was an increase of 13%. Perhaps the most dramatic influence of the extinction condition was for the animal whose data could not be collected (R12). When the extinction component was added to the schedule, responding in the initial PR component weakened to the extent that the terminal component was not reliably produced, thus precluding the analyses conducted with the other animals.

A final feature of the pause data concerns performances during the second component of the schedule (Figures 1 and 2, right panels). The results show that pausing generally was at reduced levels (10 s or less) during completion of the terminal 20 ratios of the session.

Figures 3 and 4 present data on running rates. By comparison with pausing, variations across the different ratio sizes were less systematic, and evidence for differential control

Table 3

Statistics from analyses of the data depicted in Figure 2 for R09 and R11, including slopes, intercepts, and the percentage change in slope from baseline (BL) to the succeeding experimental conditions: reversal (Rev), fixed ratio (FR), and extinction (Ext). Regression values are expressed in log units to make them comparable to those in the graphic presentations. Analyses are based on Ratios 2 through 20 of the PR schedule, except as noted.

	Reinforcement				No reinforcement			
Rat	Slope	Intercept	r^2	Change (%)	Slope	Intercept	r^2	Change (%)
R09								
BL 1	0.016	0.968	.45		0.035	0.248	.65	
Rev	0.011	1.140	.14	−31	0.032	0.365	.37	−8
BL 3	0.045[a]	0.918	.83		0.054[b]	0.022	.69	
FR	−0.018	1.194	.39	−140	0.034	0.268	.54	−37
BL 2	0.039	0.869	.90		0.058	0.173	.75	
Ext	0.044	0.886	.84	+13	0.054	0.077	.70	−7
R11								
BL 1	0.024[c]	0.710	.62		0.043	−0.068	.61	
Rev	0.019	0.975	.23	−21	0.028	−0.019	.23	−36
BL 2	0.009	1.148	.11		0.035	−0.054	.50	
FR	−0.003	0.978	.11	−133	0.021	−0.107	.53	−40
BL 3	0.008	0.995	.26		0.034	−0.076	.74	
Ext	0.015	1.019	.32	+87	0.036	−0.014	.66	+9

[a] Ratios 2 through 17.
[b] Ratios 2 through 16.
[c] Ratios 2 through 17.

by the second component of the compound schedule was absent. The most common pattern under both baseline and multiple-schedule conditions was for rates to decline as the size of the ratio increased, although in some cases response rates increased over the first few ratios (e.g., R12, BL 1). A notable finding for the percentage reinforcement condition was the absence of consistent rate differences following reinforced and nonreinforced ratios.

Finally, running rates within the terminal reversal and FR components differed depending on whether the animals were trained under the 100% or 50% reinforcement schedule. The 2 100% subjects (R10 and R12) maintained either continued low rates to the end of the session or a further decline. The 2 50% subjects, by comparison, manifested increased rates as the session progressed (more so for R9 than R11).

DISCUSSION

Baseline Conditions

Progressive-ratio schedules are coming into increasing use for the study of motivational processes, particularly in the area of behavioral pharmacology (Richardson & Roberts, 1996), and this has been accompanied by renewed interest in characteristics of the schedule itself (Baron, Mikorski, & Schlund, 1992; Cohen, Pedersen, Kinney, & Myers, 1994; Lattal, Reilly, & Kohn, 1998; Stafford & Branch, 1998). Results from the baseline phases of the present research illustrate the possibility of widening the analyses to include response patterns within the series of ascending ratios. In particular, the linear slopes of the pause functions may provide a sensitive adjunct to breaking point measures in the study of issues ordinarily pursued with PR schedules.

A consistent finding of the present research was that the pause durations increased in orderly ways with increases in the size of the ratios. These findings paralleled those of a previous study (Baron et al., 1992; see also Hodos & Kalman, 1963; Thomas, 1974). In addition, the curve-fitting procedures helped to confirm the exponential form of the pause-ratio relation during most of the progression (i.e., the function is linear when latencies are plotted on a logarithmic scale), and similar functions were recently reported by Lattal et al. (1998) in a study with pigeons. The results also indicated that running rate

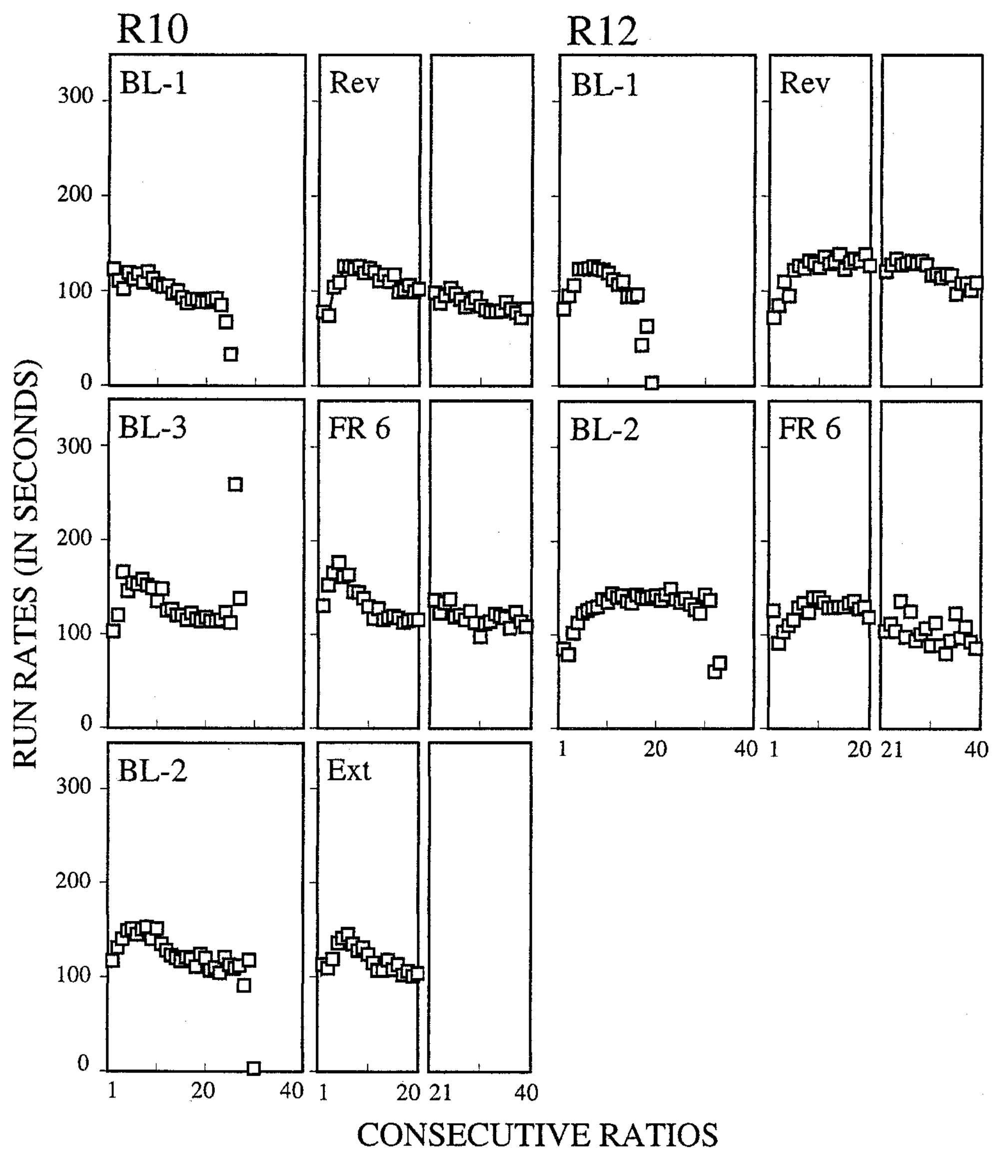

Fig. 3. Running rates as a function of ratio size for R10 and R12. Baseline performances are shown in the three left panels. The three right panels depict performances under the multiple-schedule conditions in which the 20th ratio of the progression was followed by reversed, FR, and extinction schedules (R10) or by reversed and FR schedules (R12).

is a less sensitive measure of PR performance in that declines from ratio to ratio were not as clear cut.

New findings pertained to percentage reinforcement of PR responding. The procedure of omitting reinforcement for some ratios reduced the subsequent pause without altering the exponential form of the pause-ratio functions. However, reinforcement of the previous ratio produced patterns that were not appreciably different from those observed for the 2 100% animals. Also noteworthy is that reduced pausing following nonreinforcement was not accompanied by reductions in the slopes of the functions; if anything, the slopes were steeper than those for reinforced ratios. Although percentage reinforcement had major effects on pausing, ef-

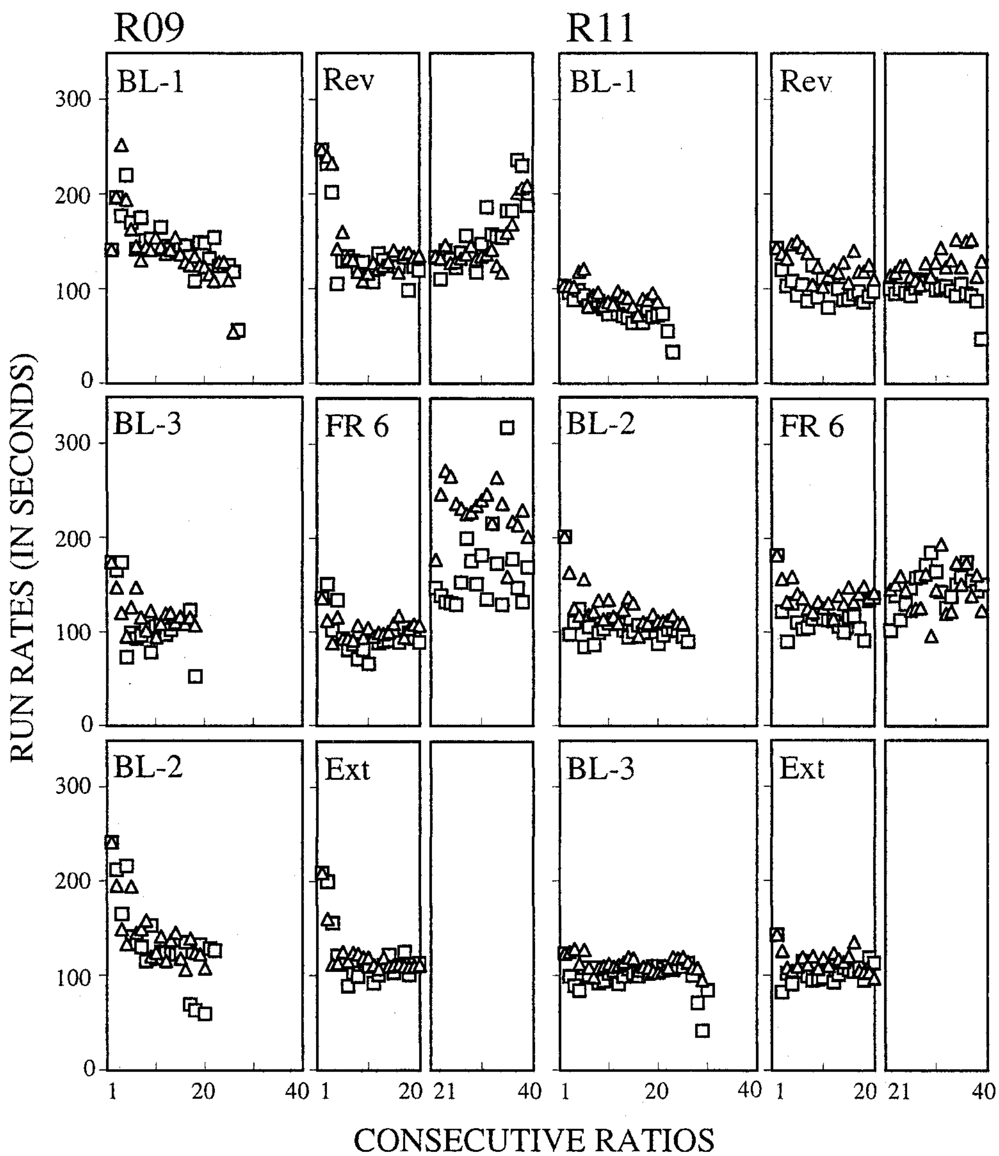

Fig. 4. Running rates as a function of ratio size for R09 and R11. Baseline performances are shown in the three left panels. The three right panels depict performances under the multiple-schedule conditions in which the 20th ratio of the progression was followed by reversed, extinction, and FR schedules (R09) or reversed, FR, and extinction schedules (R11). Responding was reinforced according to a 50% probability schedule. Running rates following reinforced ratios are designated by squares, and running rates following nonreinforced ratios are designated by triangles.

fects on running rates were minimal. Rates were approximately the same following reinforced and nonreinforced ratios, and other details were similar to those that prevailed for the 100% condition (i.e., rates decreased in an irregular fashion across the sequence of ratios).

Taken as a whole, the baseline results of the present experiment provide additional evidence for the similarity of PR and FR performances. An important point of contact is the relation of pause durations to ratio size. Results from Powell's (1968) study of FR schedules suggest exponential relations not unlike those observed in the present study. However, the apparent similarity must be qualified by differences in the way pausing was characterized. Our analysis was based on the *median* value of the distribution of pauses at each ratio level, whereas Powell employed *mean* values. Latency distributions become increasingly skewed with increasing ratio sizes, in which case the median is preferred because it is less sensitive to extreme scores. No doubt, close comparisons of pause-ratio relations require analyses of the entire distribution of pauses, but this is difficult to accomplish with PR data because exposure to each ratio size is so limited (only once per session). Despite the aforementioned problems, the present results, along with Powell's (1968), reveal the orderliness of responses to the contingencies of PR and FR schedules. In a previous discussion (Baron et al., 1992), we noted that the regularities of PR performances are remarkable in the face of the changing contingencies of the schedule and the correlated variations in the animals' daily behavior—from strong ratio control at the start to ratio strain and extinction at the end. The present results provide additional evidence that PR schedules provide an efficient way of studying issues that are ordinarily studied with FR schedules, particularly when concern is with relations between experimental variables and ratio size.

The lesser sensitivity of running rates to changes in ratio size also falls in line with what is known about FR schedules. Although the present results were somewhat more systematic that those reported by Powell (1968) for FR performances, the downward trends in both studies were modest by comparison with the changes in pausing. Discussions of FR responding have emphasized that regardless of the duration of the pause, a sustained high rate follows (the so-called break-and-run pattern; Leslie, 1996).

Another similarity between PR and FR schedules may be seen in the effects of percentage reinforcement. The results parallel those of McMillan (1971), who also found reduced FR pausing following nonreinforced ratios. However, he varied the percentage values while holding the ratio size constant. The present results show a similar effect across ratios of varying size. Reduced pausing following nonreinforced ratios also fits what is known about the dimension of reinforcer magnitude of which nonreinforcement represents the limiting case. Perone and Courtney (1992) accounted for the positive relation between FR pausing and magnitude in terms of the discriminative and inhibitory functions that can be assumed by reinforcing stimuli (see also Harzem & Harzem, 1981). The present findings on effects of percentage reinforcement of PR responding can be viewed in similar terms.

Multiple-Schedule Conditions

The second part of the experiment examined performances when the PR schedule was contained within the initial component of a multiple schedule. The precise name to give this procedure may be a matter of contention. On the one hand, the schedule contained an essential element of chained schedules in that the second component was dependent on completion of a response requirement in the first component, that is, completion of the 20th ratio of the PR schedule. However, chained schedules do not ordinarily provide unconditioned reinforcement in the initial link, whereas multiple schedules do. From this standpoint, the schedule has the properties of a multiple schedule, but one in which transition of the components is dependent on responding, as in a multiple procedure in which components change following each reinforcer delivery (rather than on the basis of the passage of time, as is often the case with multiple-schedule procedures).

Regardless of the label assigned to the schedule, results from the multiple-schedule phase are consistent with the literature on chained schedules. According to Kelleher and Gollub's (1962) widely accepted analysis, performances in the initial link of a two-link chain are controlled by the relative value of the contingencies within the terminal link. More specifically, initial-link performances are maintained by the conditioned reinforcing properties of the stimuli correlated with the link that is produced by responding. These essential relations were illustrated by Findley's (1962) classic study of variable-interval performances. He varied the reinforcement rate within the terminal component of a two-link chain and found that response rates in the initial components varied accordingly; that is, higher response rates accompanied higher second-link reinforcement rates.

The present procedure differed in a number of ways from those of Findley's (1962) study. The initial link of the present procedure contained a PR rather than an interval schedule, and the value of the terminal link was revealed by increased pausing rather than by increased response rates. In addition, initial-link responding was reinforced by food within the link as well as by production of the terminal link. Nevertheless, the same essential relations were observed. When the terminal component contained an increase in reinforcement rate (either a reversed progression or a schedule with a small FR), initial-component performance was facilitated, as shown by reductions in the slopes of the pause-ratio functions. Similar findings were evident when the terminal component was arranged to contain less favorable contingencies (extinction) in that the slopes of the pause functions steepened and animals sometimes stopped responding before the terminal component was reached.

These results bear on the variables that control conventional PR performances. The importance of control by upcoming contingencies is already known from research with FR schedules. When components contain ratios of different sizes, pausing varies as a function of the upcoming contingencies, with more favorable contingencies reducing pausing and less favorable contingencies increasing pausing. For example, pausing decreases on occasions when the size of the upcoming ratio is smaller (Baron & Herpolsheimer, 1999; Crossman, 1968) or when the magnitude of the upcoming reinforcer is increased (Perone & Courtney, 1992). An essential feature of these FR procedures is that the schedule is arranged to provide information about the upcoming contingency; this has been accomplished by correlating different stimuli with the different ratio sizes or reinforcement magnitudes. By comparison, increased pausing on PR schedules does not require addition of correlated stimuli. It is not difficult, however, to point to alternative sources of discriminative control from the PR schedule itself. The schedule's distinguishing feature is that the size of each upcoming ratio exceeds the preceding one, and a reasonable supposition is that the progressive increase in pausing reflects the animal's sensitivity to the relative differences in ratio size from one ratio to another.

Results from the multiple-schedule conditions of the present experiment show control by remote as well as local events. A general finding was that the pause-ratio functions were exponential, and this form was maintained regardless of the events within the second component. As shown by the results in Figures 1 and 2 (see also Tables 2 and 3), the manipulations altered the size of the exponent (the slope) but did not have systematic influences on the shape of the function. If control over pausing were local, one would expect greater influences of the terminal link on ratios late in the initial component than on earlier ones, in which case the forms as well as the slopes of the functions would be expected to vary. However, we could not find evidence that the degree of control depended in systematic ways on the degree of separation of a particular ratio from the terminal link, or that the pattern of changes deviated from exponential increases. To the contrary, the characteristic finding was that all points in the progression were altered to the same degree, regardless of their distance from the onset of the terminal link.

A final matter pertains to investigations of the interval counterpart of the present reversal procedure. Innis and Staddon (1971) trained pigeons with schedules in which the interval durations systematically increased and decreased, in other words, increasing and decreasing progressive-interval schedules rather than increasing and decreasing progressive-ratio schedules. A striking aspect of their findings was the regularity with which the duration of the fixed-interval (FI) postreinforcement pause tracked the descending as well as the ascending intervals of the schedule. By comparison, onset of the reversal of the PR schedule in the present study was accompanied by a rapid reduction in pausing to levels that accompanied the shorter ratios. Moreover, there was no evidence that this transition was any less abrupt than was the case when the schedule changed to FR 6.

We cannot provide a completely satisfactory account of these different outcomes in the absence of more systematic study. However, given that the primary difference between the procedures resides in the schedule—interval versus ratio—this seems to be a reasonable place to seek clarification. The FI pause is often seen as a response to temporal cues, and since Innis and Staddon's (1971) original work evidence has accumulated that animals are proficient in forming such discriminations. By comparison, the variables controlling the FR pause (and by extension the PR pause) are more problematic. Although the ratio pause also has been described as the consequence of the nonreinforcement of responding immediately following the reinforcer (e.g., Nevin, 1973), we also cited evidence suggesting that pausing may be controlled more by the amount of upcoming work. The present ratio-reversal procedures were arranged so that work increased in one limb of the ratio sequence and decreased in the other, and onset of the second stimulus signaled the start of the more favorable component. Viewed within the framework of Kelleher and Gollub's (1962) chaining analysis, the correlation of the second component stimulus with a progression of reduced work should give the second component stimulus both conditioned reinforcing and discriminative properties. The conditioned reinforcing properties of the stimulus would be expected to strengthen responding within the ascending limit (as evidenced by the variations in slope) and discriminative properties that controlled reduced pausing in the second component (as evidenced by the abruptness of the change).

Unlike ratio schedules, the interval pause is largely controlled by the time to the expiration of the particular interval. From this standpoint, an ascending and descending series of interval durations simply exposes the animal to a series of temporal stimuli whose discriminative properties control pauses of appropriate durations. As for the absence of differences between the reversal and FR 6 conditions of the present experiment, we must appeal to the possibility that the procedural difference was insufficient to produce a behavioral difference; in other words, there was a ceiling effect. Of course, it also is possible that our procedures were insufficiently precise to produce differences that otherwise would occur.

In summary, the present results illustrate a number of commonalities between PR schedules and schedules containing FR contingencies. Performances varied as a function of ratio size, and, as with FR schedules, the most sensitive aspect of the response pattern was the postreinforcement pause. The special feature of the PR schedule is that the contingencies become more demanding as the subject progresses through the schedule. The results support the notion that, from the very start of the schedule, performances reflect the subject's sensitivity to the fact that each ratio will exceed the previous one.

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